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Taking the Hype out of 5G IoT

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Introduction

Now that 3GPP Release 15 is set, many people think that 5G is "ready to go". Far from it.

In fact, only the first step has been taken. Participants in the 3GPP committees accelerated the schedule for TDD networks that optimize spectral efficiency for broadband applications. They've set the basic frame structure and the scheme for 5G flexibility. But the IoT waveforms are still not settled. This report is our attempt to indicate the key issues and the likely waveform choices for various 5G cases.

For 5G IoT applications, everyone agrees that two general groups of applications are important: Ultra-Reliable Low Latency Communications (URLLC) and Massive IoT. These two market segments require very different characteristics in the radio:

- URLLC devices will be synchronized, will use an orthogonal waveform, and will use substantial signaling overhead. These radio setup conditions lead to spectral efficiency in the range of 0.5 to 1.0 bps/Hz, but can provide 99.999% reliability within a set response time.
- Massive IoT applications focus on cost and long battery life, so spectral efficiency and power efficiency are key elements. To save on cost and power, uplink transmissions will be asynchronous, using "controlled collisions" to handle large numbers of uplink messages. The waveforms will be non-orthogonal and signaling will be minimized.

URLLC: How it will work

To achieve high reliability, URLLC variations of 5G will utilize OFDM in a way that is very similar to the broadband case. However, different options will be chosen for the subframe setup, including wider sub-carrier spacing. This means that the network will intentionally sacrifice spectrum in order to improve latency.

At the same time, heavy overhead is expected in the URLLC case. A heavy signaling overhead will be used for higher reliability. (As much as 52% of data transmitted is overhead, in the case of 5G NR at 120 kHz sub-carrier spacing and 7 symbols per slot)

While many people are considering unsynchronized uplink setup using Non-Orthogonal Multiple Access (NOMA) techniques, we don't think these concepts will be used for

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URLLC customers very much. Instead, we expect a more synchronized, managed messaging setup.

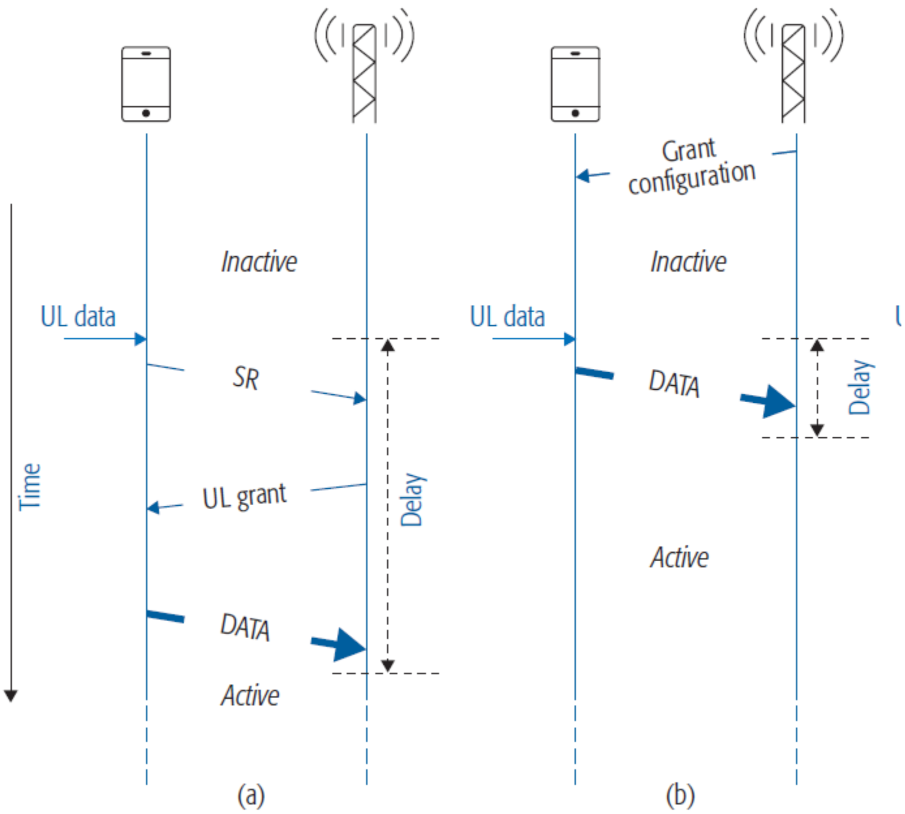

Figure 1: Uplink scheduling options: a) Scheduling Request; b) Semi-persistent Scheduling

Sources: Ericsson

To further enhance reliability, some operators will use "multi-connectivity" which can be viewed as a way to send data over two bands. If one band has interference or RF fading issues, the other band is likely to be okay. In this way, when each RF band has a reliability of 99.9%, (Packet Error Rate of 0.1%), the combination of two bands would theoretically be 0.1% x 0.1% = 0.000001% or 99.9999% reliability. Of course, reality won't be that good but when we get to serious trials we expect to see this approach used to guarantee 99.999% radio reliability. Again, we are using up more spectrum in order to improve reliability.

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	LTE (15 kHz, 2 symbol TTI)	5G CP-OFDM	Multi-connectivity 5G CP-OFDM
Latency for one 32 B packet	0.86 ms	0.33 ms	0.33 ms
Retransmission Delay	1.4 ms	0.31 ms	0.31 ms
Spectral Efficiency at 10 dB SNR	0.2 bps/Hz	0.5 bps/Hz	0.25 bps/Hz
Reliability at 1 ms	99.999% theoretical We have doubts about this because no retransmissions possible in 1 ms	99.999%	99.9999%

Figure 2: Comparison of LTE, 5G URLLC, and Multi-Connectivity 5G URLLC

Sources: Ericsson, Mobile Experts

Note: Using Semi-Persistent Scheduling (SPS) for uplink in all cases

URLLC: Is it worthwhile?

Should the operators give up valuable spectrum for critical IoT applications? After all, we will achieve 4-8 bps/Hz in mobile broadband usage, and only 0.2 to 0.5 bps/Hz for URLLC. But it's important to consider how much money the operator makes per MHz of spectrum, not the number of bits.

In broadband applications, the operators will sell 5G data for less than $1 per GB, a reduction from $5-10/GB today. However, in high-reliability IoT applications where the operator can GUARANTEE 99.999% packet success, we estimate that the operator can charge over $5,000 per GB! Therefore the comparison really looks like this:

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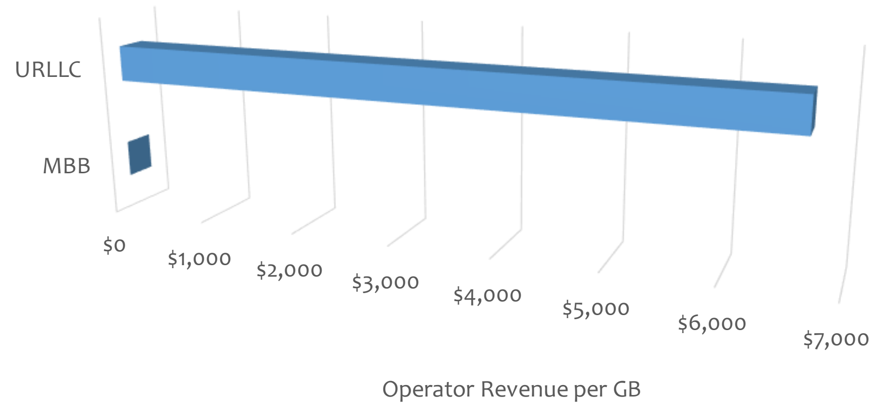

Figure 3: Operator Revenue per GB of data: MBB vs. URLLC

Source: Mobile Experts

So, despite the tradeoffs in spectral efficiency and high signaling overhead, IoT is a winner for the mobile operator.

Because the operator doesn't need to set aside spectrum resources exclusively for IoT, they get the benefit of improved "financial efficiency" whenever IoT data is transmitted. When the IoT devices are quiet, the operator can go back to using all of their 5G time slots for broadband data.

Massive 5G IoT Waveforms: There's a decision coming

To achieve low cost and low power consumption, the 3GPP standards committees still need to select between a long list of non-orthogonal waveform choices, each of which is optimized for slightly different conditions. It's unlikely that 3GPP will choose more than one option here, because the IoT devices must interoperate in the field.

Recent activity at 3GPP has been developing in "Study Items" that will lead to "Work Items" and eventually become released standards, possibly in the second half of 2019.

So far, the industry consensus is clear that a non-orthogonal multiple access (NOMA) approach will be best. Compared with orthogonal multiple access (OMA) approaches, NOMA allows improvements in uplink throughput and density (performance under collision conditions), so almost everybody supports this as a general direction. However at least 15 versions of NOMA have been proposed by various players:

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NOMA Format	Stands For	Company proposing it	Description
SCMA	Sparse Code Multiple Access	Huawei	Multi-dimensional constellation, sparse mapping
RSMA	Resource Spread Multiple Access	Qualcomm	Symbol-level scrambler Asynchronous in single carrier form
MUSA	Multi-User Shared Access	ZTE	Random complex spreading sequences
PDMA	Pattern Division Multiple Access	CATT	Symbol-to-resource mapping patterns
LCRS	Low Code Rate Spreading	Intel	Low code rate spreading factors
IGMA	Interleave-Grid Multiple Access	Samsung	Interleaved symbol level grid mapping
LDS-SVE	Low Density Signature—Signature Vector Extension	Fujitsu	RB-based sparse mapping patterns
LSSA	Low code rate and Signature based Shared Access	ETRI	Low rate coding scrambling
NOCA	Non Orthogonal Coded Access	Nokia	Spreading using LTE reference signals
IDMA	Interleave Division Multiple Access	Nokia	Low code rate interleaving
SSMA	Short Sequence Spreading-based Multiple Access		Spreading based technique
RDMA	Repetition Division Multiple Access	Mediatek	Symbol level interleaving
GOCA	Group Orthogonal Coded Access	Mediatek	Orthogonal and non-orthogonal handled separately
WSMA	Welch-bound Spreading Multiple Access	Ericsson	Low-complexity

Figure 4: Table of NOMA options

Source: 3GPP proposals by each company

We're still a long way from resolving questions about how NOMA will be implemented. After reviewing some recent technical papers, the performance of these various approaches don't seem very different to me. They all make different use of spreading factors, code modulation, interleaving, and scrambling but the performance is almost identical anyway. In the two charts below, the performance of NOMA compared with OFDMA is significant, but the difference between NOMA variations in terms of spectral efficiency and reliability is small.

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The differences between NOMA formats are more likely to be seen in device density. The spreading and scrambling schemes (RSMA, and WSMA are leading candidates) have highest density potential, while interleaving approaches may have advantages in HARQ effectiveness and other areas.

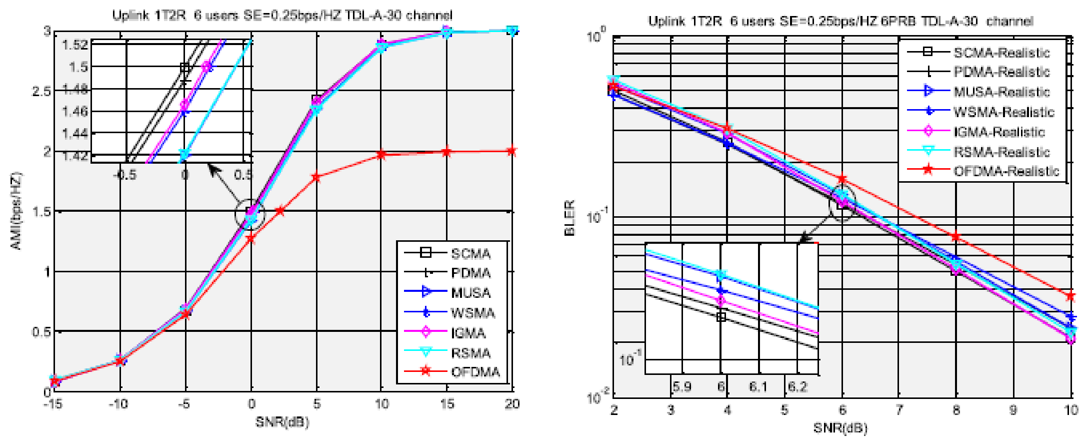

Figure 5: Spectral Efficiency and Reliability Performance of NOMA options vs OFDMA

Source: Z. Wu, et al. *IEEE Access*

The differences between these formats may be minor, but that does not mean that companies will not battle for their variation to be adopted. Ericsson, Huawei, Nokia, Intel, ZTE, and Qualcomm all have submitted proposals to the RAN committees, and the battle will rage over the next year. The battle is not really about performance, but about who will own the patents to the underlying waveform.

The market is not ready for another air interface standard anyway, so we don't see any reason for the 3GPP group to resolve this question very quickly. They are likely to spend the next year hashing out a common view of NOMA, then releasing in as part of Release 16 during late 2019.

Is 5G massive IoT worthwhile?

Earlier, we determined that high-reliability IoT can be more profitable for a mobile operator than broadband services. What about massive IoT? Is NOMA-based 5G IoT going to be cheaper and better than NB-IoT?

There are pros and cons here. We cannot see a clear case for massive IoT using 5G, but there are some possibilities. Here are some strategic thoughts:

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- **BOM Cost**: If we compare an NB-IoT module with a 5G NOMA module, we don't see much cost savings. In fact, when we take the impact of China's NB-IoT subsidies into account, we believe that the NB-IoT option will be cheaper. NB-IoT modules are Chinese-government-subsidized by about $2.50 today, covering all of the R&D costs so that Huawei/HiSilicon can sell the NB-IoT chipset for only $2.25 in 2018. That's only about 10% higher than LoRa chips. We expect a 5G NOMA chipset to cost about $4.00.

  Note that the Chinese government is heavily subsidizing NB-IoT chips because Huawei owns the basic patents on NB-ioT (acquired from Neul). It's a team effort in China to make NB-IoT succeed worldwide. We don't expect the Chinese government to subsidize a 3GPP NOMA format, where Huawei doesn't own the basic patent.

- **Power Consumption**: The power consumption of NOMA-based 5G should be lower than NB-IoT devices. This could be a differentiator for applications where small bursts of uplink traffic happen extremely often. The savings comes from the likely choice of an asynchronous NOMA approach, which reduces the signaling overhead so that a small burst of traffic will require less energy out of the battery. At this point in time, we see NB-IoT devices offering 10 year battery life, so this improvement would not be used for longer battery life but for increases in the frequency of transmissions. Your water meter could report data every minute instead of every 15 minutes. The need for more frequent bursts is likely to happen, but we don't know how strong that need is yet.

- **Density:** This is one area where 5G NOMA architectures could yield an advantage. The target for 5G has been set by 3GPP at 1 million devices per square kilometer, but in fact the real test here is the number of data sessions that can be made simultaneously for a narrow slice of spectrum. NOMA "overloading factors" can range as high as 400%, which we understand to mean that through a combination of modulation, power, and coding schemes four data sessions can share the same resource block.

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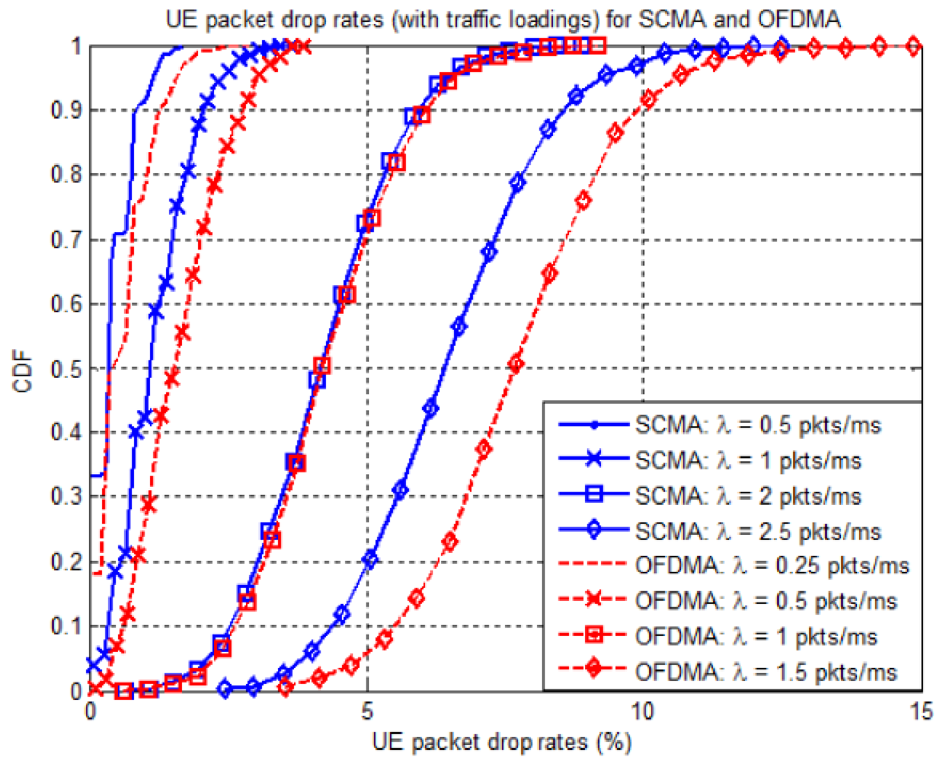

Figure 6: SCMA advantage in connection density compared with OFDMA

Source: Huawei

The research is not very clear yet on which NOMA schemes provide the best density of data sessions. In general, the spreading and scrambling-based formats will provide the best density of connections—almost double compared with LTE as shown in the chart above. However, until heavily loaded field testing is performed we are not able to predict which NOMA format will rise to the top.

5G Network Slicing

In the end, we see some differentiation in reliability and latency for 5G, but the cost is higher than NB-IoT so we have been forecasting a pretty small market. There is one wild card that could change our view: Network slicing.

Several companies have commented in our IoT interviews that as they enter the IoT data market they need GUARANTEED connectivity. Auto companies, factories, drone pilots, electric utilities, and others are interested in setting aside resources to ensure that they'll never lose a packet.

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In LTE, mobile operators are unable to sign up to this kind of guarantee, because every part of the network is set up to handle a limited amount of capacity. Even if there's enough radio capacity, under peak conditions the network is likely to hit its limit upstream in the baseband processing, authentication, policy, billing, or other core network functions.

5G network slicing basically allows for the operator to set aside a portion of capacity at every level of the network, so that even under extreme loading conditions the network will handle the high-priority traffic.

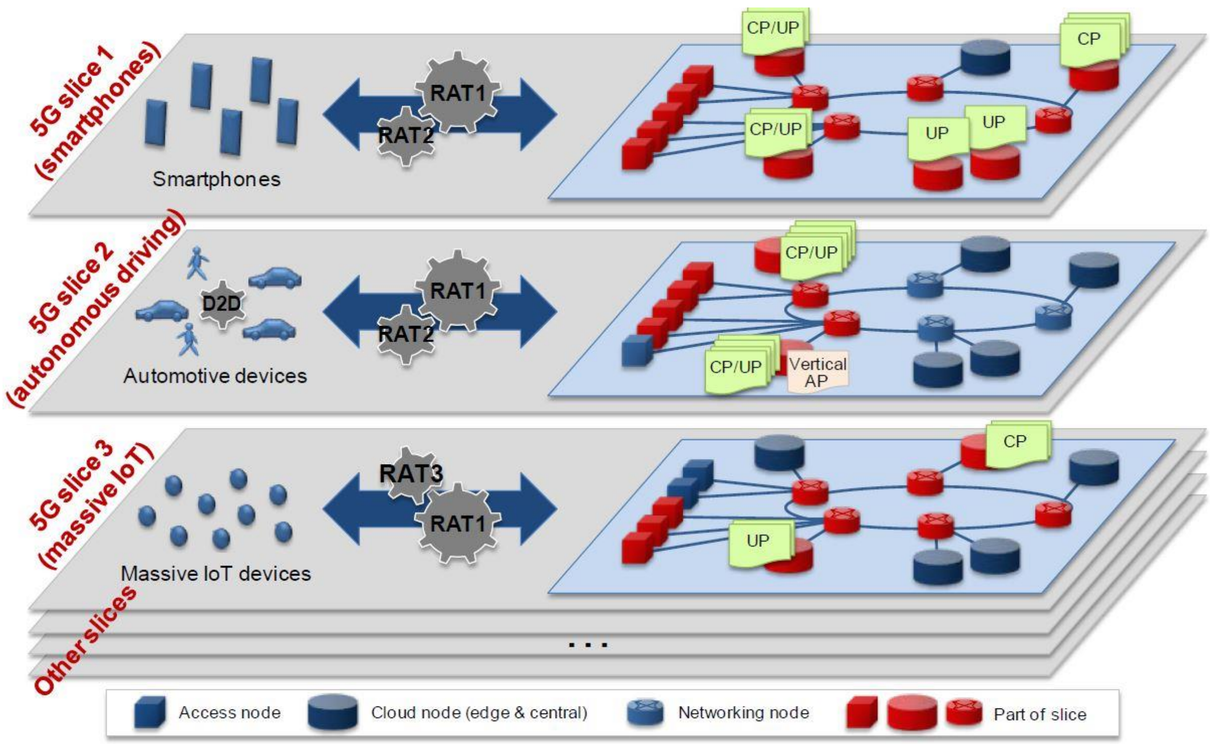

Figure 7: Network Slicing Diagram

Source: 3GPP

Currently, the Mobile Experts forecast assumes that high-reliability, low-latency applications will use the network slicing feature to improve on overall reliability, and operators will be able to charge a premium in exchange for guaranteed connectivity. In the case of massive IoT, it's not clear what network slicing will actually achieve, and whether any cost savings will be associated with the network slice for Massive IoT. Without cost savings, the added reliability of high priority in Massive IoT has little value, since simple repetition of the message can get the packets through eventually.

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Conclusions

The IoT market is growing quickly with LoRa and NB-IoT today. When we look at the two main scenarios for 5G IoT, we can see how the URLLC features of 5G can add value to the existing IoT options. On the other hand, we don't think that 5G Massive IoT connectivity will be useful for about 10 years because the level of traffic won't require the higher density associated with NOMA waveforms for a long time.

Waiting 10 years to actually implement 5G Massive IoT might be okay, because the LoRa and NB-IoT devices deployed in 2018 won't need a battery recharge until 2028 anyway.

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